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THE SPONTANEOUS HEATING AND IGNITION OF HAY AND OTHER AGRICULTURAL PRODUCTS[1]

By Dr. C. A. BROWNE

U. S. BUREAU OF CHEMISTRY AND SOILS

THE production of heat, as a manifestation of vital activities, was associated at first almost entirely with the processes of animal life. This is not surprising when we consider the effect of the transpiration of large quantities of water from the immense leaf surfaces of growing plants which tends to keep their temperatures below that of the surrounding air.

The original observation of Lamarck[2] in 1777 that the fleshy spike or spadix of the flowers of *Arum maculatum* at a certain stage of growth was perceptibly warm to the touch first called the attention of scientific men to the heat-producing power of growing plants. Senebier[3] in 1800 confirmed this observation of Lamarck and at the same time noted the additional fact that this production of heat was especially pronounced in the presence of oxygen. The connection of this observation with the familiar oxygen respiration of animals was indicated later by the experiments of Saussure[4] in 1822, since which time the validity of a true respiration process by plants, in which oxygen is consumed and carbon dioxide evolved, has been universally recognized.

The intensity of this heat production by plants and its relation to oxygen consumption were examined by other investigators in succeeding years. In experiments by Kraus[5] in 1882 upon the spadix of flowers of *Arum italicum* a maximum temperature of 44.7° C.

[1] Address of the vice-president and retiring chairman of Section C—Chemistry, American Association for the Advancement of Science, Atlantic City, December, 1932.
[2] Lamarck, "Flora française." 1777.
[3] Senebier, "Physiol. végétale," III, 314. 1800.
[4] Saussure, *Ann. Sci. Nat.*, 21, 285, 1822; *Ann. Chim. et Phys.* (2), 21, 279, 1822.
[5] Kraus, *Abhandl. Naturf. Gesell. Halle*, 16, 1882.

was observed. During the production of this heat large quantities of carbon dioxide were evolved, and in a few hours a third or more of the dry substance of the spike (consisting of reserves of starch and sugar) was consumed.

If transpiration and the radiation of heat are retarded, as when the organs of plants are heaped together in large piles, the production of heat by vegetable cells becomes very apparent. The production of heat in piles of grain and in heaps of grass was probably observed by man in prehistoric times. It was also observed at a very early period that under certain conditions some plant materials, as hay or straw, might undergo so great an increase of temperature during spontaneous heating as to burst into flames. In later times, when men began to speculate as to the cause of things, the phenomenon of the spontaneous heating and ignition of plant materials was ascribed to the presence of an occluded fire or heat, and this explanation was retained by Bacon,[6] Boerhaave[7] and other philosophers until comparatively modern times.

The German botanist Goeppert[8] showed in 1830 that when a mass of barley grains was allowed to germinate in a wooden box, temperatures as high as 50° C. might be obtained. He did not differentiate, however, between the heat evolved by the respiration of the sprouting grain and that developed by the vital processes of adhering micro-organisms. This distinction was first clearly demonstrated by Cohn,[9] a plant physiologist of Breslau, who showed in 1890 that the first production of heat by the respiration of germinating seeds came to an end at about 40° C., which coincided with the thermal death point of the young plants. Cohn then observed after a short pause a second rise of temperature to about 65° C., which he attributed to the vital processes of thermogenic micro-organisms.

The maximum temperature observed in the most carefully controlled experiments upon the heating of plant materials by biological agencies does not usually exceed 70° C., which is about the thermal death point of most vegetating micro-organisms. This is some 160° C. lower than the temperature necessary for the ignition of hay, and the problem which has perplexed scientific men for so long is how to explain the great increase in temperature between the death point of the thermogenic micro-organisms and the point of spontaneous ignition.

[6] Bacon, "Novum Organum." Translated by P. Shaw, 2 v. London. 1802.

[7] Boerhaave, "A New Method of Chemistry." Translated from the printed edition by P. Shaw and E. Chambers. London. 1727.

[8] Goeppert, "Ueber die Wärme-Entwickelung in den Pflanzen." 272 pp. Breslau. 1830.

[9] Cohn, "Ueber Wärme-Erzeugung durch Schimmelpilze und Bakterien." Jahrg. Schles. Gesell., 68: 23–29. Breslau. 1890.

There have accumulated during the past fifty years many detailed accounts, by careful observers, of the visible phenomena of the spontaneous ignition of hay. These accounts all largely agree as to the main facts, so that the one specific instance which we have selected will be sufficient for general purposes of illustration. This typical case, related in *Liebig's Annalen* in 1873 by the German agricultural chemist Ranke,[10] is of classic interest, for its publication acted as a stimulus in drawing the attention of scientific men for the first time to a careful study of the complicated problem of the spontaneous ignition of hay.

A partial translation (by the author) of Ranke's original article is as follows:

On my estate Laufzorn, which is situated south of Munich about four hours by post near the Grünwald forest, a burning odor was observed on the morning of October 19, 1872, in the west corner of a large massively constructed barn.

In this section of the barn was stored a part of a crop of rowen that had been harvested upon the estate and unloaded in two adjacent piles, one of which contained about 22½ tons and the other about 15 tons.

This rowen had all been harvested in apparently well dried condition during excellent weather between the 5th and 10th of August. During the whole of September there was noticeable only the customary strongly aromatic odor of hay which increased in intensity until finally on the 17th and 18th of October a perceptible burnt odor began to be noticed. This empyreumatic burnt odor had become so strong on Saturday morning, October 19, that my manager was convinced the interior of the mow had caught fire. He determined at once to remove the hay as carefully as possible and in case fire should be discovered to extinguish it with a large quantity of water.

All available buckets, casks and other containers were accordingly filled with water upon the scaffold of the barn above the rowen and at 10: 30 A. M. the removal of the hay was very carefully commenced. . . .

As the removal now began to be pushed more vigorously from the top there were suddenly observed at a depth of about 5 feet several sparks. At the same time smoke and flashes of sparks were suddenly observed on one of the wagons, upon which the latest removed portions of rowen were being hauled from the barn. This was about 1: 30 P. M.

The entire mow and the loaded wagon were now drenched with water. The rowen that was now being hauled out was of a deep brown color and was spread out upon the grass near a pond situated behind the barn.

From now on the removal of rowen could be performed only with constant drenching with water, since almost every forkful as soon as it was taken out began to glow. It was also frequently necessary to pour water again upon the material which had been loaded since even the boards of the wagon repeatedly broke into flames. Even the rowen that had been spread out on the grass near

[10] Ranke, "Experimenteller Beweis der Möglichkeit der Selbstentzündung des Heues." *Liebig's Ann. Chem. und Pharm.*, 167: 361–8. 1873.

the pond reignited repeatedly, so that it had to be extinguished three times. The material outside in the open broke out into actual flames, which was prevented inside the barn by the constant energetic drenching with water. It might be mentioned in this connection that on the following day the grass sod, upon which the removed rowen had been spread, was found to be completely burned. . . .

Finally after it had become dark the work of removing the burning material from the barn was completed. The burnt mass formed, as it were, the core of the pile and was estimated to have a diameter of about 11 feet at the top; it extended downwards to about 1½ feet from the floor where the diameter of the hot portion, however, had narrowed down to about 4 to 5 feet. The burned area extended backwards to within about 1½ feet from the rear wall of the barn.

The condition of the burnt mass was that of an actual carbon with a retention, however, of its original structure. The form of every spear of grass and of every flower could be plainly recognized. If this grass carbon was rubbed upon paper, the latter was colored black.

Ranke, acting upon a suggestion by Professor Buchner,[11] of the University of Munich, attributed the repeated spontaneous ignition of his hay to the strong absorptive power of the hay charcoal for atmospheric oxygen.

The pyrophoric carbon theory of Ranke was at once confronted with a serious objection, which was the difficulty of explaining the origin of the heat that is necessary to raise the temperature of the hay to the point of carbonization. When a pile of green grass begins to heat, the incipient elevation of temperature is commonly attributed to the oxidation of sugars by the action of enzymes in the plant cells and in the adhering micro-organisms that produce fermentation. The life of the plant cells and of the micro-organisms is, however, destroyed before the temperature reaches 80° C., and the activity of the oxidizing enzymes can hardly be supposed to exceed 100° C., which is some 50° C. below the temperature at which hay begins to carbonize and some 130° C. below the temperature at which hay ordinarily ignites. It is the bridging over of these large unexplained gaps in the increase of temperature in a heating haystack that constitutes the real problem of its spontaneous ignition.

It is not possible in the limits of space at our disposal to describe all the theories which have been proposed to explain this difficulty. Laupper,[12] the well-known Swiss authority upon the spontaneous ignition of hay, supposes pyrophoric iron, and not pyrophoric carbon, to be the causative factor. Others have supposed spontaneously inflammable gases, such as phosphine, to be responsible for the ignition. It has been also supposed by some that there are two kinds of heat production, one due to vital causes at low temperatures and one due to chemical causes at high temperatures. This conception, however, is baseless, for the entire production of heat, from the first rise in temperature to the point of ignition, is due to the effects of chemical reactions; therefore scientifically no differentiation can be made between vital heat and chemical heat.

In order to explain how a heating haystack can catch fire the German bacteriologist Miehe[13] assumed that pyrophoric carbon can be formed at the comparatively low temperature of 70° or 80° C. The following passage is translated from his original article upon the subject:

I believe that carbonization may indeed take place even at this temperature, for it must be considered that the action continues for a considerable time, even for months. The hay undergoes so to speak a dry distillation, in which the elements of the organic compounds are rearranged; new volatile compounds of simpler composition are set free and the material remaining behind approaches more and more the composition of pure carbon. That oxidations still take place above 75° and 80° has already been indicated by the experiments of Schlösing and of Boekhout and DeVries. The carbon is of an extremely fine porous character, each cell retaining its structure. It is plausible to suppose that such carbon may condense oxygen in a manner similar to finely divided platinum (platinum sponge). It would then, perhaps similar to platinum sponge, acquire a strong oxidizing power and perform oxidations that would be possible normally only at a much higher temperature. It could exercise this oxidizing effect either upon itself or upon the absorbed easily oxidizable gases, such as hydrogen, phosphine, volatile hydrocarbons (methane, ethylene, etc.), that are produced by the slow distillation or decomposition of the organic constituents of the hay. Such oxidations might perhaps take place even in undisturbed piles of hay after a certain interval of time when the ingress of oxygen was limited. The temperature would then slowly increase. Or, as seems more probable, the oxidations would develop only when an abundance of oxygen can enter, or in other words when the pile is torn open or when air passages are created intentionally or unintentionally. In fact, it is the general consensus of opinion (see Medem and other writers) that ignition is only produced when free entrance is given to the air by the insertion of poles, construction of air pits, opening up of the stack, etc.

The assumption of Miehe that pyrophoric carbon is produced at low temperatures has been adopted by other students of the problem. The supposition, however, is hardly tenable, for there are many cases

[11] Buchner, *Liebig's Ann. Chem. und Pharm.*, 167: 361. 1873.

[12] Laupper, "Die Neuesten Ergebnisse der Heubrandforschung," *Landw. Jahrb. Schweiz Jahrg.*, 34: 1–54. 1924.

[13] Miehe, "Die Selbsterhitzung des Heues. Eine biologische Studie." 127 pp. Jena. 1907.

recorded where spontaneous ignition of hay has taken place without any evidence of carbonization and indeed within only a few days after it has been stored away, whereas Miehe supposes that the action continues "for a considerable time, even for months."

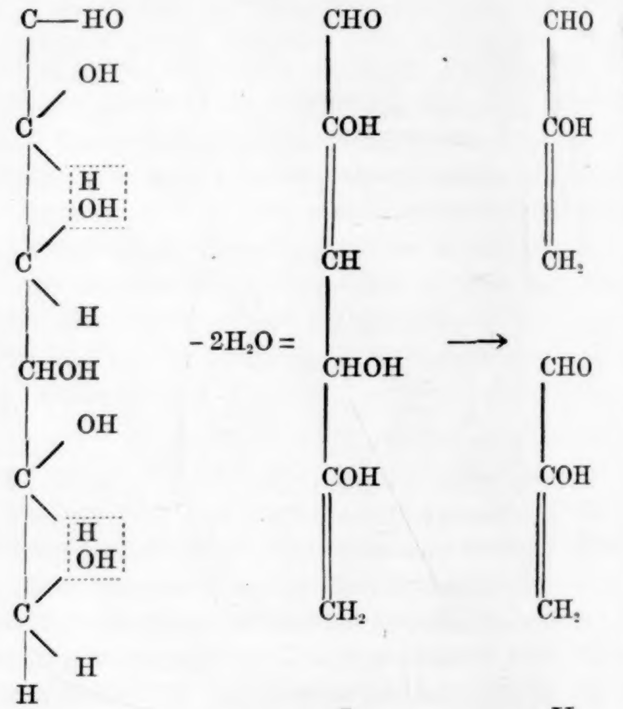
In 1929 the author[14] suggested as a possible solution of the problem of spontaneous ignition the formation, by micro-organisms under anaerobic conditions, of unsaturated unstable intermediary compounds which, in the sudden exposure of the interior of the fermenting mass of hay to the air, absorb atmospheric oxygen with so much avidity that the temperature is rapidly raised not only above the death point of the micro-organisms but even to the point of ignition of the hay. This spontaneous ignition may take place almost instantly, as James, Bidwell and McKinney,[15] of the Department of Agriculture, have observed in the case of heating horse manure, or it may take place more slowly, according to the rapidity with which the outside air gains access to the hot pocket in the interior of the hay. In other words, the micro-organisms that produce the incipient fermentation of the hay by enzyme action or otherwise are responsible for the preparation of the mine that may, or may not, later be sprung with the spontaneous ignition of the mow or stack.

The splitting-off of water from the organic constituents of plants is one of the most common reactions attending the deterioration of agricultural products, and one effect of this change, of great importance in the study of the problem of spontaneous ignition, is the accumulation of residues of greater and greater calorific energy. The significance of this reaction in plant life and in fermentation was pointed out as far back as 1870 by the German chemist, Adolph Baeyer,[16] who in a very suggestive article published in the *Berichte* of the German Chemical Society may be said to have blazed the way to an understanding of some of the reactions that take place in the decomposition of plant materials by micro-organisms.

Baeyer supposed that as a first step in this decomposition the elements of water are stripped off from the sugar molecule with the formation of unstable intermediary products, which, by the readdition of water and in other ways, finally give rise to lactic acid, alcohol, carbon dioxide and the other end-products of fermentation. The splitting-off of water from the carbohydrate molecules results in the removal of H and OH groups from the carbon chains and in the formation of unsaturated intermediary compounds with carbon atoms that are united by double bonds. These compounds are of a very labile reactive character and by the subsequent readdition and reelimination of water pass through various modifications before the final end-products of the fermentation are reached.

Since the time of Baeyer's classical paper there have been almost innumerable speculations as to the nature of the intermediary compounds which are produced in the fermentation of sugars. Among the most plausible of the theories which have been proposed is the one of Wohl[17] and Neuberg[18] that the first compound produced by the stripping-off of water from the sugar molecule is an unsaturated intermediary substance that breaks down immediately into two molecules of an enolic form of methyl glyoxal as shown by the following equation:

1.



Sugar | I Intermediate | II 2 Mols. Methyl glyoxal enol

The unsaturated enolic form of methyl-glyoxal has not been isolated from fermentation mixtures, and it probably only exists momentarily. Methyl glyoxal itself ($CHO–CO–CH_3$) has, however, been detected in fermentation products, and this fact is a strong argument in favor of the Wohl-Neuberg theory of fermentation.

[14] Browne, "The Spontaneous Combustion of Hay." Tech. Bulletin No. 141, U. S. Dept. of Agriculture. September, 1929.

[15] James, Bidwell and McKinney, "An Observed Case of Spontaneous Ignition in Stable Manure." *Jour. Agr. Research*, 36: 481–5. 1928.

[16] Baeyer, "Ueber die Wasserentziehung und ihre Bedeutung für das Pflanzenleben und die Gährung." *Ber. Deutsch. Chemisch. Gesell.*, 3: 63–75. 1870.

[17] Wohl, "Die neue Anschauung über den chemischen Verlauf der alkoholischen Gärung." *Biochem. Zeits.*, 5, p. 45. 1907.

[18] Neuberg, "Zuckerumsatz der Pflanzenzelle." Handbuch der Biochemie, II Aufl. Bd. 2, Jena. 1925. For a full discussion of the Wohl-Neuberg and other theories regarding the fermentation of sugars see Oppenheimer's "Die Fermente," Bd. II, p. 1450, V Aufl. 1925.

A direct proof of the formation of unsaturated highly reactive enolic compounds in the decomposition of sugars has recently been furnished by Nelson and Browne,[19] of the Bureau of Chemistry and Soils, in the isolation of the so-called "glucic" acid

$$\begin{array}{c} COOH \\ | \\ COH \\ \| \\ CH_2 \end{array}$$

corresponding to the enolic form of methyl glyoxal. This acid is produced by the action of weak calcium hydroxide upon a dilute solution of glucose at 70° C. in the absence of air. The calcium salt of the acid deposits almost immediately; it absorbs oxygen from the air with the greatest avidity and with an intense evolution of heat. It is perhaps by the rapid oxidation of unsaturated highly reactive intermediary substances similar to this that the heat of a fermenting haystack is produced. In this connection it might be noted that Lange[20] has recently obtained evidence of the production by *B. coli* of an unsaturated very unstable highly oxidizable intermediary product, which is similar in some of its reactions to propiolic acid $CH \vdots C \cdot COOH$. It is possible that the acid detected by Lange is closely related to the glucic acid of Nelson and Browne.

The oxygen which is needed for the transformation of the intermediate unsaturated compound may come in part from the air; but it may also be supplied by the decomposition of water, in accordance with the simultaneous reduction-oxidation reactions which have been especially studied in Germany by Wieland.[21]

Tschirch[22] has proposed a modification of this reduction-oxidation theory to explain the spontaneous ignition of hay. He criticizes the hypothesis of the formation of pyrophoric carbon at 70° C., as suggested by Miehe, and as a substitute for this supposes that the ignition is due to the rapid evolution of oxygen from the organic constituents of the hay as a result of the action of reducing enzymes under anaerobic conditions. To quote from Tschirch's original article (author's translation):

> If half-dried hay is packed tightly together in a thick layer, the most easily reacting oxydases are the first to become active. This first phase of the reaction is the first nondangerous stage that is associated with only a slight increase of temperature. It is an oxidation or combustion process that involves a consumption of oxygen. As soon as the oxygen is used up, however, the activity of the reductases sets in. They find points of attack in all the oxygen-containing constituents of the cell contents and cell membrane. . . . Cellulose, for example, contains 51 per cent. and aspartic acid 48 per cent. oxygen. The reduction process which advances rapidly with rising temperature is the second dangerous stage which sets in about 50°–70°. At these ranges of temperature the reductases apparently attain their optimum of activity. Very favorable conditions for their action exist especially in the interior of a haystack where all the oxygen is consumed by oxydases. The disintegration process reaches its maximum, therefore, in the interior of the haystack and can proceed here to complete carbonization, preceding which in a preliminary stage, there are first produced brown colored intermediary products, that still contain H and O, and which also constitute the basis for the color of "brown hay." The abundant supply of oxygen, that is suddenly made available in the reduction process within the firmly packed haystack, where no outlet is possible for the generated gas, leads finally as in so many other cases to an explosion, that is to say to a rapid combustion of the available carbon compounds, both those reduced as well as those still unreduced. The heat that is generated in the reduction process can not alone explain the ignition since this never mounts to the ignition temperature of cellulose. It is only the generation of oxygen and the occurrence of an explosion that explains satisfactorily the ignition.

The hypothesis of Tschirch has not met with general acceptance, principally for the reason pointed out by Hildebrandt[23] that the development of high temperatures in heating hay does not take place under the complete exclusion of the air, as would be expected if his explanation were correct, but only after atmospheric oxygen has gained access to the fermenting material.

There is not time, nor would it be altogether profitable in this connection, to discuss the possible rôle of the reductases, oxydases, peroxydases, catalases and other enzymes that are supposed to take part in the fermentation of plant materials. They play unquestionably a very important part in the chemical reactions which are involved in the spontaneous heating of plant materials, although not necessarily an indispensable part. The writer[24] described in 1929 a peculiar spontaneous decomposition of sugar cane molasses that was perfectly free from micro-organisms and enzymes, in which the sugars were gradually converted into dark-colored organic compounds of higher and higher carbon content. These changes, which are the result of obscure internal chemical reactions, can

[19] Nelson and Browne, "The Properties and Chemical Constitution of Glucic Acid." *Jour. Am. Chem. Soc.*, 51, pp. 830–6. 1929.

[20] Lange, "Production of an Unsaturated Compound by *B. coli* in a Synthetic Medium." *Proceedings* for the Soc. of Experimental Biology and Medicine, p. 1134. June, 1932.

[21] Wieland, "Ueber den Mechanismus der Oxydations-Vorgänge." *Ber. Deut. Chem. Gesell.*, 45 (2606); 46 (3327); 47 (2085); etc. 1914, etc. For a full review of Wieland's theory see Oppenheimer's "Die Fermente," Bd. II, pp. 1283–95. 1925.

[22] Tschirch, "Die Entzündung der Heustöcke." *Mitt. Naturf. Gesell. Bern*, pp. 133–137. 1917.

[23] Hildebrandt, "Beiträge zur Frage der Selbsterwärmung des Heues," *Zentbl. Bakt.*, (II) 71: 440–90. 1927.

[24] Browne, "The Spontaneous Decomposition of Sugar Cane Molasses," *Ind. Eng. Chem.*, 21: 600–6. 1929.

be explained only upon the basis of a progressive splitting-off of water from the sugar molecules, similar to those which have been previously described. As a result of this continual stripping-off of hydrogen and hydroxyl groups, residues are left which under certain conditions release their energy almost explosively in the "hot room" of sugar factories with the evolution of acid vapors, carbon dioxide and other gaseous decomposition products. A very high temperature is developed, with the result that the molasses froths and boils over, being finally converted into a porous carbonaceous residue.

We have so far considered only the heat evolution which results from the rapid oxidation of the unsaturated compounds that are produced by the splitting-off of water from sugar molecules. A certain part of the celluloses and hemi-celluloses of hay is hydrolyzed into sugar in the initial stages of the fermentation process, and the sugar thus formed must be considered as sources of heat producton in addition to the sugar originally in the hay.

There are in the hay, however, large quantities of insoluble cellular materials, such as cellulose, lignin and pentosans, which are not hydrolyzed in this way, but which nevertheless undergo decomposition in the anaerobic fermentation of hay by the same process of splitting-off of water. Analytical determinations show that these cellular components of the hay undergo in the process of sweating a continual loss of oxygen and hydrogen in the form of water, with the accumulation of unsaturated residues that become richer and richer in carbon. As this decomposition progresses, the hay changes in color first to yellow, then to light brown (the color of the so-called brown hay), then to dark brown and finally to black, the product in the last state approaching the composition of the so-called hay carbon. It is not pure carbon, however, and contains only from 50 to 70 per cent. of carbon, according to the degree of alteration which the cellular substance of the hay has undergone.

It can now be readily seen that with the formation and accumulation of unsaturated residues under anaerobic conditions in the porous cellular materials of hay the accidental entrance of air into the interior of the stack may bring about such a rapid absorption of oxygen at the points of unsaturation that the temperature may be quickly raised to the point of ignition. The reaction is perfectly similar to the familiar spontaneous ignition of cotton whose fibers have been coated with thin layers of an unsaturated vegetable oil, such as that of linseed. It is not necessary, therefore, to assume with Miehe, and other students of the subject, that ignition takes place only as a result of the formation of pyrophoric carbon or, according to Laupper, with the formation of pyrophoric iron. The unsaturated highly reactive decomposition products in a fermenting haystack are produced at comparatively low temperatures far below those necessary for the production of pyrophoric carbon or pyrophoric iron. Many spontaneous ignitions of hay have occurred when there was no blackening of the material, such as would be produced as a result of carbonization. The traces of iron compounds in hay no doubt act as catalysts in the process of spontaneous ignition, similar to the action of traces of iron and cobalt compounds in the spontaneous ignition of an oily piece of cotton, but such iron can not be regarded as the fundamental cause of the ignition.

The exact coincidence of all the conditions necessary for the spontaneous ignition of hay is fortunately of infrequent occurrence. If the hay is too wet it will not ignite; if the hay is too dry it will not ferment. If there is a constant unimpeded circulation of air through the interstices of the hay, the unsaturated intermediate substances are oxidized as fast as they are formed and there is no accumulation of those easily decomposable residues which by their final almost instantaneous oxidation raise the temperature in a few minutes from 80° or 90° to the point of ignition of the hay. The opening up of a hot haymow is, therefore, a hazardous operation and should only be done when every precaution has been taken to extinguish the conflagration that may immediately break out, such as happened in the case narrated by Ranke and such as has happened in so many of the other cases that have come under observation. The first quenching of the outbreak of fire with water does not remove the danger. The unstable rapidly oxidizable residues are still there and, with the evaporation of the water from the hot hay, may ignite spontaneously again and again, as indicated by Ranke, whose description of the phenomenon has been repeatedly confirmed by other observers.

Statistics show that spontaneous ignition of hay occurs almost exclusively in large mows and stacks. The large stack not only creates a better insulation against radiation of heat from the inside and a slower penetration of atmospheric oxygen from the outside during the precursory period of anaerobic fermentation, but it also offers a more favorable opportunity for creating somewhere in the mass of material the exact conditions of moisture, temperature and oxygen penetration that are necessary for spontaneous ignition. When fermentation begins there is an immediate migration of moisture from the warmer to the cooler zones of the stack; a cool section that was previously dry enough to withstand fermentation may acquire by condensation sufficient moisture from a contiguous hot fermenting zone to become a good medium for the rapid development of micro-organisms. In this way a single load of undercured hay in

the center of a large mass of well-cured hay may start fermentations throughout the whole mass of material. With the migration of these fermenting zones from point to point there may finally be found somewhere a zone having the optimum conditions of moisture, temperature and air supply that lead finally to ignition. If this necessary coincidence of optimum conditions does not obtain, the stack, after several months of fluctuating changes of temperature, begins to cool down, with perhaps an occasional sporadic elevation of temperature at isolated points. The impeded penetration of air prevents the accelerated oxidation of the unstable organic residues; these are only very slowly oxidized and when the stack has finally approached the temperature of the outside air, these once highly oxidizable complexes are so sufficiently stabilized that the stack may be opened up without danger.

While this sketch of the chemical processes involved in the spontaneous heating and spontaneous ignition of hay is probably in general correct, there are many details of the problem that must be worked out under carefully controlled quantitative conditions. We need observations upon the production of heat, consumption of oxygen and evolution of carbon dioxide, water, etc., by large masses of fermenting hay in a respiration calorimeter, for it is only in this way that we can determine how much of the heat is produced as a result of anaerobic reduction-oxidation reactions and how much is produced by atmospheric oxidation. We need more observations upon the elementary analysis and heats of combustion of hay at various stages of spontaneous heating. We need further research on the nature of the solid, liquid and gaseous organic compounds that are produced in both the anaerobic and aerobic fermentations of hay, particularly of those elusive intermediate compounds which are the most difficult of all to detect. We need more knowledge of the phenomena of moisture migration and heat transference in large masses of hay. We need also more exact information as to the temperatures of ignition of hay at different stages of the fermentation process. When fundamental knowledge upon these and other points has been acquired we shall be able to visualize more clearly the details of the complicated reactions that take place in the spontaneous heating and spontaneous ignition of hay and other agricultural products and to arrive at the best practical means for reducing the enormous economic losses from this cause.

BREAD QUALITY OF WHEAT PRODUCED IN AQUEOUS CULTURE MEDIA

By Dr. W. F. GERICKE

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Among the causes of differences in the bread properties of wheats, those related to the quality of their proteins are of much interest to cereal chemists. Quality in flour as affected by the character of protein appears to be a very definite entity when expressed by baker's marks, and while the loaf of bread is and perchance always will remain the ultimate criteria of quality, nevertheless the concept "quality of protein" is still an intangible term, lacking a precise chemical definition. The interested trades feel a real need for simple and reliable tests of protein quality, which apparently may vary from season to season in accordance with the vagaries of climate; consequently experiments were designed to attack the problem from another angle, namely, by the water culture method, whereby specific treatment could be accorded the material selected for milling and baking operations.

Wheat protein is supposed to be identical in chemical composition among varieties. The fact of differences in the character of bread due to protein would, in lieu of differences in quantity thereof, be accounted for by differences in its physical character. It is known that the physical state of colloid particles varies with the nature of the medium surrounding them, and as plant sap is a more or less concentrated salt solution, it appeared as not improbable that variation in the quality of wheat protein might reflect certain features of plant sap. The fact of variation in the concentration and composition of plant sap with cultural treatment and also the differences in physical character of starches derived from the same source also were suggestive as to the type of experiment required to throw more light on the protein problem.

To obtain such data, the writer grew wheat in aqueous culture media on a scale large enough to provide samples for milling and baking operations. The plants were grown in a series of tanks filled with water, over which a seed bed was mounted, and which permitted production of a crop in culture media that could be altered at will.

Full description of the technique of crop production in a water medium by mass planting will appear in due season. As a preliminary note, however, it may

be stated that the essential features of the method consisted primarily of (1) a seed bed mounted over and in contact with a water surface, so that the crop could be planted by mere broadcast scattering of the seed and grown to maturity without further replanting; and (2) the use of "fertilizing units," a single bottle per tank containing all elements required for growth of plants in water which being once applied requires no further attention and thus eliminates much of the tedium associated with classical water culture experimentation. The seed bed consisted of poultry netting stretched tightly over the top of the tanks. Burlap placed on the netting furnished support for the seed sown thereon. A thin layer of sawdust covered the seed to maintain the required moisture conditions for germination. With the sprouting of the seed, the roots penetrated the burlap and extended into the water and the plants grew to maturity in place as seeded. The "fertilizing units" contained ten elements, of which those required in relatively large amounts were supplied by the ordinary grade of fertilizer applied to land and those required in small amounts were supplied from equally inexpensive sources. Ordinary tap water was used. From 800 to 1,400 grams of dry grain was grown per reservoir, having 25 square feet of seedbed. The maximum yield obtainable per 25 square feet of water surface has not been determined, but apparently is decidedly larger than can possibly be obtained per equal area of soil surface.

Three sets each of an array of seven varieties were grown, two in water, one in soil. Of the former, one was located under glass, the other in the open field. The soil set consisted of plats in the open field. All samples grown in liquid media received similar treatment up to the heading stage. When that state of development was obtained, the solution of each reservoir was drained, the fertilizing units removed and fresh water supplied. Then the treatment was altered: One reservoir out of every set of two received a new fertilizing unit, thus reproducing therein for the final growth period the same culture medium in which all samples were started. The other reservoir received no salts, the crop being allowed to grow to maturity in a nutrient-free medium. Thus the length of the period during which nutrients were available for absorption was made to differ. In the one case, the salt content of the mature plant was expected to be low, as no nutrients were available for absorption during the latter part of the growth period. In the other case, it was expected to be high because all elements were available in relatively large quantities throughout the entire growth period. The soil-grown crop received a very heavy application of $NaNO_3$ at approximately the same growth stage as that at which the crop grown in liquid medium had the nutrients removed. The conditions in regard to the supply of nutrients in the soil-grown crop were in essence similar to those of the crop grown in liquid medium which contained nutrients throughout the entire growth period of the plants, save as to amounts of nutrients available which were assumed to be less in the soil than in the liquid medium.

From an agronomic standpoint, yield is an important consideration in growing a crop for investigations dealing with the bread quality of wheat. In field culture, variation in yield may or may not reflect itself in the baking properties of the flour. However, as these experiments were not designed to show the conditions under which such correlations are obtained—or failed to be obtained—no consideration will be given to the physiological properties of the culture media in respect to their effects upon yields, save in one aspect. With all varieties grown in liquid media, both under glass and out of doors, larger yields of grain were obtained from the reservoirs that did not contain any nutrients during the latter part of the growth period, than were obtained from those which contained an abundance of nutrients throughout the entire growth period of the plants. These results, at first consideration somewhat surprising, are, however, in full accord with the observed facts of nature, namely, that for a considerable portion of their growth, many plants rooted in soil thrive in a media low or nearly depleted of available nutrients, granted of course that the supply was adequate during their early growth stage. This condition exists because plants have a higher rate of absorption of nutrients than the soil has of making nutrients available.

Analyses of the crops revealed that the percentage of water soluble and also total ash in the plants grown in the liquid media varied with the treatments, and was higher in the cultures where nutrients were available throughout the entire growing period than where they were absent during the latter part of the growth period. Likewise, the ash of the grain varied similarly with the treatments, but it was of decidedly lower value than that of the straw. The grain harvested from the reservoirs in which the supply of nutrients was not restricted was not so well filled as was that obtained from the reservoirs in which nutrients were restricted. The filling of the individual kernels in a head of wheat appears to be largely a matter of adequate production of carbohydrates by the plant and its translocation into the kernels. It appears, therefore, that the failure of the grain to fill properly was, in part, due to the excessive absorption of some of the inorganic nutrients, and the consequent effect in the restriction of the production of carbohydrates. Within limitation, the amount of

carbohydrates in wheat plants appears to be inversely related to that of the absorption of inorganic elements, but whether this relation applied to all elements expressed as total ash or only certain ones thereof, was not deducible from the data. The percentage of ash of the patent flour also varied with the treatments, but it was of decidedly lower value than that of the grain, the range being 0.4 per cent. to 0.7 per cent.

Milling and baking operations were performed according to the directions of Standard Mills for their experimental laboratories. Apparently the yield of the various mill products of wheat was not altered by the treatments. Only patent flour was used for the baking tests and the bread produced therefrom showed decided differences in quality, both as to varieties and the cultural treatments employed.

The data obtained are as yet too fragmentary to indicate how the nature of plant sap affects the colloidal state of the proteins and starches. Apparently the ash content of flour throws no light on the matter. The ash content of the straw varied from 3.5 to 17 per cent. among varieties and treatments, and while the quality of the bread did not vary correspondingly with that of the ash, it was evident that some type of relation did exist.

It soon became apparent that, in order to clarify this relation, it was necessary to differentiate two fractions of the total amount of each element absorbed, one on which yield was dependent, and one on which it was not. The fact that yield of grain was not restricted by the absence of nutrients in the culture medium during the latter growth period of the wheat plants indicated the arrival of a stage in their development when the absorption of nutrients no longer had nutritional functions. This growth phase was not identical with all elements. Neither was it fixed for any element, as conditions which affected the rate of supply of nutrients during the early growth of plants affected the time of arrival of that period. The crop-yielding power of various increments of any element absorbed by plants from the culture media varied with the time of their absorption; those which were absorbed early possessing greater power than those absorbed late. Corresponding to this difference in yielding power, other differences in the properties of the absorbed nutrients may be assumed. Among these are composition and concentration of plant sap. While the amounts of nutrients absorbed at maturity do not give a true picture of these properties of sap during growth, nevertheless they do indicate the direction of possible fluctuations in these characters. It appears safe to assume that the concentration of the sap of plants due to the nutrients on which yield is dependent is less than that due to nutrients which can not function causatively. The absorption, occurring too late, becomes excess because of the brevity of time remaining for utilization. The quantity absorbed too late to function causatively is superimposed upon that which functions causatively with corresponding effect on concentration of the plant sap.

By precluding the absorption of nutrients during the latter growth phase of wheat, the relation of the crop-producing value of varying quantities of an element to that of yields of grain can be determined. With some qualification, this relation can be expressed as a straight line function for all elements. At no period of the development of wheat will the absence of either nitrogen or phosphorus in the culture medium preclude reproduction, and the magnitudes of yield become a given multiple of the quantities of either of these elements absorbed during the early growth phases of the plants. This straight line relation is contingent on sufficient time subsequent to the absorption of the quantities in question to permit the plants to elaborate the materials into the maximum amount of product possible which is defined by the lowest percentage of the element in the composition of the mature product. Absorption of these elements occurring too late in the life of wheat to effect yield reflects itself in the composition of the plants, and is expressed for the specific elements in question by the degree it exceeds the minimum percentage obtainable in the mature product. But in the case of iron, calcium or potassium, the relation is not so simple because the absence of any one of these elements at certain growth phases will preclude reproduction, even though their presence in the medium at a former growth phase had resulted in considerable vegetative development. Only after certain minimum quantities have been supplied to bring the plants to such a state of development that the first increment supplied thereafter will effect grain production, are yields proportional to varying amounts of the element absorbed.

It is inferred from these relations between yields and quantities of various elements required that the physical properties of the plant sap arising from the truly nutritive quantities of each of the elements absorbed does not vary save by those factors which are part and parcel of growth. Changes are features of growth. A definite type of reactions or characteristics prevails, or follows one after another, in the constitution of plant sap with the circumstances of growth. But the plant is always exposed to secular forces which may intensify or lessen the rate of changes of the components of the truly nutritive character of plant sap. Nutrients which can not function productively thus become the cause of variation of the physical properties of plant sap because they are superimposed on those which define the type.

Wheat varieties vary more or less markedly as to the amount of an element required per unit weight of grain produced. Furthermore, the ash content of their straws varies with the elements absorbed. Subtracting the amount of nutrients required for any measure of yield of any variety from that of its ash, one obtains a measure of the quantity of material which caused secular variation in the plant sap. Better bread was obtained from wheats having a relatively large excess of salts in the straw beyond the minimum required for the yield obtained than from those having none or only a small excess.

OBITUARY

RECENT DEATHS

CHARLES WILFORD COOK, professor of economic geology at the University of Michigan, died on February 17 at the age of fifty years. He had been connected with the department of geology for twenty-five years and was well known for his work in economic, and especially in oil, geology.

DR. CHARLES SPENCER WILLIAMSON, head of the department of internal medicine of the University of Illinois Medical College, Chicago, died on February 15 at the age of sixty years.

Nature reports the death of Lieutenant Colonel John Stephenson, known especially for his work on the oligochaetes, from 1912 to 1920 professor of biology and principal of the government college at Lahore, India, and later until 1929 lecturer in zoology at the University of Edinburgh.

PROFESSOR ALFRED SCHAARSCHMIDT, head of the Institute of Chemical Technology at the Technische Hochschule, Charlottenburg, has died at the age of forty-nine years.

THE death is announced of Dr. Johannes Schmidt, the biologist and oceanographer of Copenhagen.

SCIENTIFIC EVENTS

THE SCHOOL OF MEDICINE OF ROSARIO

A CORRESPONDENT of the *Journal* of the American Medical Association reports that the board of directors of the School of Medicine of Rosario, Buenos Aires, recently resigned because the directors have had some difficulties with the students. The new board of directors has expressed a wish to nullify many of the regulations made by the previous boards for the management of the school. The School of Medicine of Rosario is dependent on the University of Litoral. The university controls seven medical schools and also other scientific centers. One of those centers, the Escuela de Agronomía y Veterinaria of the province of Corrientes, has more teachers than students. As a result of the economic conditions, the government recently reduced the yearly allowance of the University of Litoral, which in turn reduced the allowances given to the medical schools and scientific centers under its control. The medical school of Rosario could have met this deficit by reducing some of its expenses. There are, for instance, three courses on the same subject (psychiatry); many other subjects which are not strictly of a university nature could have been discontinued. However, in order to economize, the salaries of the professors were reduced. Drs. Ruíz and Hug, directors of the institutes of anatomy and of pharmacology of the medical school of Rosario, whose contracts expired, refused to sign a new contract at a reduced salary. Then the board of directors decided to eliminate the course of pharmacology. However, the students and some professors opposed dropping the course and finally they decided to continue it. The vacancies left by Drs. Ruíz and Hug were reported so that applications for the positions could be made. The monthly salary to be given professors in those positions is 500 pesos ($130) as directors of the institution and 300 pesos ($78) as professors, making a total of 800 pesos ($280) a month. However, this amount is more theoretical than real, because, owing to taxes, the salary is reduced to 700 pesos ($182). The full time professors of the medical school of Rosario had 1,300 and 1,500 pesos ($338 and $390), respectively, for their monthly salary. By giving them only 700 pesos the school saves 1,500 pesos a month, although the full-time system is sacrificed. Those full-time professors have devoted the past ten or fifteen years to laboratory research and now they are compelled to practice medicine or do other things for a living, while their places are taken by others who have not had so much experience. There were five full-time professors in the medical schools of Argentina. By the elimination of these two there are now only three (Drs. Houssay, Lewis and Elizalde).

AUSTRALIAN FOSSILS FOR THE HARVARD MUSEUM

THE largest and most complete specimen of a plesiosaur ever discovered in Australia is included in the collections made by William E. Schevill, assistant

curator at the Harvard Museum of Comparative Zoology. Mr. Schevill returned in December from an 18-months expedition to Australia, and a preliminary investigation of his findings is now in progress.

The most important discovery, it is believed, is the skeleton of the plesiosaur. It is about two thirds complete, making possible for the first time an accurate reconstruction. Previous finds in Australia have been only fragments. The Harvard specimen is now being prepared for mounting, although it will be some months before it is ready for display.

The remains of various species of Plesiosaurus have been found previously in Europe and America, and the present finding of a more complete example of the Australian plesiosaur will make possible important comparisons. The Australian specimen is known as "Kronosaurus queenslandicus."

Previous specimens have been found in England, Germany, the United States—New Jersey, Kansas and Wyoming. In some American examples, stones of various sizes, from a quarter of an inch to 4 inches in diameter, were found in the position of the stomach, and are supposed to have been swallowed as aids to digestion. The fossil remains at Harvard are being carefully studied for evidence of similar feeding habits among the Australian species.

Mr. Schevill's find was located on the ranch of R. W. H. Thomas, near Richmond in northwestern Queensland, which was a submerged area during the Cretaceous period. In addition to this skeleton, he has brought back a large number of specimens, including not only fossils but also a series of present-day animals. The entire shipment was made in 95 cases, weighing in all eight tons.

The Australian collection has been made as part of the museum's program of obtaining field specimens from every section of the world. Many of these will be arranged in "systematic collections," showing graphically the history of evolution. The exhibition collections are used as a supplement to text-books by Harvard University students in courses on zoology and paleontology.

ADMINISTRATION OF THE BOULDER DAM PROJECT AREA

THE Secretary of the Interior, Dr. Ray Lyman Wilbur, on February 15 approved the bills for administration of the Boulder Canyon Project area, introduced by Senator Hayden, of Arizona, and Congressman Arentz, of Nevada. The Secretary says:

> Hoover Dam is now under construction and storage of the waters of the Colorado River in the immense reservoir to be created thereby will begin, probably, early in 1935.
>
> This largest artificial reservoir in the world possesses great recreational and educational possibilities which should be conserved. The bill provides for the efficient and economical accomplishment of the purpose by entrusting this responsibility to the National Park Service, while the Bureau of Reclamation administers the area so far as it has to do with the primary purposes of the original legislation. In this way the building up of duplicating organizations is avoided.
>
> The bill also determines the limits essential to the project and definitely establishes the reservations. It vacates withdrawals heretofore made and restores about 1,400,000 acres to entry.

No claim of exclusive federal jurisdiction is made as to the new reservation and Secretary Wilbur announces that none will be. Accordingly, the laws of Nevada and Arizona, including those as to schools, taxation and elections, will not be disturbed in the new reservation set up by the bill.

As to the smaller federal reservation, heretofore established by order of Secretary Wilbur, at Boulder City, the bill proposes that Nevada shall have full rights of taxation therein after construction of the dam is completed; that Nevada shall immediately have the right, in the Boulder City area, to collect a property tax for school purposes and a mining tax, and to conduct schools.

The Secretary states the department does not propose to submit any estimates of appropriations during the fiscal years 1933 and 1934 for recreational development.

Secretary Wilbur considers the bill very important and urges its enactment at this session of Congress. He says of it:

> The bill replaces uncertainty with certainty, solves numerous existing administrative difficulties, makes possible orderly planning for the future and provides fully for the interests of the United States and of adjacent communities as to the development and use of this highly important area.

NEW PHARMACOPOEIAL VITAMIN ADVISORY BOARD

THE Board of Trustees of the United States Pharmacopoeia has announced the appointment of a Pharmacopoeial Vitamin Advisory Board consisting of

- Dr. Lafayette B. Mendel, Yale University.
- Dr. H. C. Sherman, Columbia University.
- Dr. E. M. Nelson, Protein and Nutrition Division, Bureau of Chemistry and Soils, U. S. Department of Agriculture.
- E. F. Kelly, Baltimore, Maryland, representing the United States Pharmacopoeia Board of Trustees.
- E. Fullerton Cook, Philadelphia, Pennsylvania, representing the United States Pharmacopoeia Committee of Revision.

The appointment of this board has been the outcome of several pharmacopoeial conferences, held in New York during the past year, attended by vitamin experts in the United States, who have recommended a revised standard for the vitamin A and vitamin D potency of the official cod-liver oil. The same group has approved assay methods for both vitamins and these assay methods are proposed for official adoption.

Fifteen vitamin laboratories in the United States, one in London and one in Norway are now determining the vitamin A and vitamin D potency of a special "Reference Cod-Liver Oil," supplied by the U. S. Bureau of Fisheries. This oil will be available in a few months for distribution by the United States Pharmacopoeial Vitamin Advisory Board. A nominal charge will be made for this "Reference Oil" which will have known vitamin A and vitamin D activity, expressed in International Units. This oil will be distributed through the office of the Chairman of the U. S. P. Vitamin Board to be addressed at 43d Street and Woodland Avenue, Philadelphia, Pa.

THE WASHINGTON MEETING OF THE AMERICAN CHEMICAL SOCIETY

LEADERS of science and industry will address the eighty-fifth meeting of the American Chemical Society in Washington during the week beginning March 26. Seventeen of the professional divisions of the society, embracing every principal field of chemistry, will hold sessions. The history of chemistry will be traced in exhibits at the Library of Congress.

Researches presented by workers in the Federal Service will bring to the attention of the nation contributions to science made by the government departments. Numerous committees in the District of Columbia are making arrangements for an extensive program of inspection of federal laboratories and scientific services, the aim being to convey knowledge of the development of Washington as one of the great science centers of the world.

Many of the leading industries as well as universities, colleges and other institutions will send representatives. Dr. Irving Langmuir, associate director of the General Electric Company, will give a public address on "Surface Chemistry" in Constitution Hall, 18th and D Streets, N.W., on Wednesday, March 29, at 8:30 P. M.

The formal sessions will open with a general program on Monday, March 27, following a meeting of the directors of the society, at which Professor Arthur B. Lamb, of Harvard University, president, will preside. Speakers at this general session and their topics will include:

Charles F. Kettering, chief engineer of the General Motors Corporation, Detroit, "The Relation of Chemistry to the Individual"; Harry L. Derby, president of the American Cyanamid Company, New York, "The Relation of Chemistry to the State"; C. M. A. Stine, vice-president of E. I. du Pont de Nemours and Company, Inc., Wilmington, Delaware, "The Relation of Chemical to Other Industry"; Professor Hugh S. Taylor, head of the department of chemistry, Princeton University, "Chemistry—its Interrelations with Other Sciences."

Agriculture and food, petroleum, biological chemistry, chemical education, medicinal chemistry, rubber, sugar, dyes, industrial and engineering chemistry, organic, and physical and inorganic chemistry are among the general fields to be covered at sessions of the professional divisions. The Division of Chemical Education, of which Professor Lyman C. Newell, of Boston University, is chairman, plans a symposium on "Recent Developments in Various Chemical Industries." The purpose of this symposium is to acquaint the chemistry teachers of the country with industrial developments.

The Division of Biological Chemistry, of which Professor J. B. Brown, of the Ohio State University, is chairman, will hold a symposium on "Anemia"; the Division of Agricultural and Food Chemistry, headed by Professor H. A. Schuette, of the University of Wisconsin, one on "Insecticides."

The Division of Industrial and Engineering Chemistry, of which Professor D. B. Keyes, of the University of Illinois, is chairman, will hold a symposium on "Glass" in conjunction with the Glass Division of the American Ceramic Society.

The Division of Physical and Inorganic Chemistry, of which Professor W. A. Noyes, Jr., of Brown University, is chairman, will hold six sessions, including a symposium on "Electrolytes," under the chairmanship of Professor Victor K. LaMer, of Columbia University, and a symposium on "Analytical Chemistry," under the chairmanship of Professor N. H. Furman, of Princeton University. The Division of Petroleum Chemistry, headed by F. W. Sullivan, of Whiting, Indiana, is arranging for two sessions, one being devoted to a symposium on "Properties of Hydrocarbon Mixtures." Other divisional meetings are scheduled.

A demonstration of dust explosions has been arranged by the Division of Chemical Engineering, Bureau of Chemistry and Soils, for Thursday, March 30, at Arlington Farm. The demonstration, which will be in charge of D. J. Price, will show in miniature what takes place when organic dusts explode under various conditions met in industry and how the hazards from these dusts can be largely minimized.

Special events include a visit to Edgewood Arsenal, called "the chemists' contribution to national defense." There will be a demonstration of chemical warfare weapons by the First Chemical Regiment and of airplane dispersion of smoke by officers of the Air Corps.

SCIENTIFIC NOTES AND NEWS

The School of Mining of Leoben will confer an honorary degree in mining engineering on President Hoover for his services to mining and technology and for his literary work. It was planned to confer the degree on March 2 in the presence of representatives of the government and all the Austrian universities. The diploma was to be received by Gilchrist Baker Stockton, the United States Minister.

Dr. Wallace W. Atwood, president of Clark University, who was an American delegate to the Pan American Institute of History and Geology meeting in Rio de Janeiro, reached New York on February 22. After the meeting, which ended early in January, Dr. Atwood went to Peru and Bolivia, where he studied the highland country for Incan and pre-Incan archeological information. Dr. Atwood was elected president of the institute for the meeting to be held in Washington in 1935.

Dr. Jonathan C. Meakins, director of the department of medicine at McGill University, has been elected president of the American College of Physicians and Surgeons for 1934.

Dr. Charles Edward Munroe, chief chemist for explosives at the United States Bureau of Mines, emeritus professor of chemistry at George Washington University, has been appointed honorary chairman of the committee making plans for the Washington convention of the American Chemical Society, which opens on March 26. Dr. Munroe, who is now eighty-three years old, is the sole surviving charter member of the society, formed in 1876.

Professor Thomas C. Esty, from 1922 to 1929 dean of Amherst College and for many years a member of the department of mathematics, has been appointed by the trustees to be the first vice-president at the recommendation of President Stanley King. Professor Esty will exercise the power and carry on the work of the president in the absence of Dr. King.

Dr. Willard E. Hotchkiss, formerly dean of the Stanford Graduate School of Business, has been appointed president of the Armour Institute of Technology in Chicago.

Dr. Victor Goldschmidt, professor of mineralogy at the University of Heidelberg, celebrated his eightieth birthday on February 10.

The council of the Physical Society, London, has awarded the tenth Duddell Medal to Professor Wolfgang Gaede, director of the Kaiser Wilhelm Institute of Physics at Karlsruhe, for his work on the design and production of high vacuum pumps.

The Royal Dublin Society has awarded the Boyle Medal to Dr. Paul A. Murphy, professor of plant pathology at University College, Dublin.

Dr. Austin F. Rogers, professor of mineralogy at Stanford University, has been elected to membership in the Mineralogical Society of France.

At Columbia University Dr. Arnold Knapp has been retired with the title of professor emeritus of ophthalmology. Dr. Howard B. Adelmann has been appointed assistant professor of anatomy; Dr. Karl Meyer, assistant professor of biological chemistry, and Dr. Richard Thompson, assistant professor of bacteriology.

Dr. Lewis R. Hill has been appointed professor of bacteriology at Loyola University School of Medicine, Chicago, succeeding Dr. Emil Weiss, who resigned recently because of ill health.

Dr. Paul Blum has been nominated professor of therapeutic hydrology and climatology at Strasbourg, and Dr. Cristol, professor of biological chemistry at Montpellier, in succession to Dr. Derrien.

It was announced in Science last week that Captain Charles L. Oman had been appointed surgeon-general of the U. S. Navy. This appointment, like others made by the outgoing administration, has not been confirmed by the Senate.

Captain William Chambers has been transferred from the division of planning, Bureau of Medicine and Surgery, U. S. Navy, Washington, D. C., to duty as director of the American Scientific Mission, Port au Prince, Haiti, succeeding Captain Montgomery O. Stuart.

D. L. Van Dine, until recently an entomologist with the Tropical Research Foundation in Cuba, has been appointed head of the Division of Fruit and Shade Tree Insects of the Bureau of Entomology, U. S. Department of Agriculture. This appointment relieves Dr. C. L. Marlatt, chief of the bureau, of the direction of federal investigations on the insect enemies of fruit.

Dr. R. von Ihering has been commissioned by the Federal Government of Brazil to study the prospects of fish culture in the reservoirs of the arid regions of Northwest Brazil (frontier of the states from Piauhy to Bahia). Biologists interested in limnology will be given transportation facilities for the study of subjects correlated with fish culture. Candidates recommended by their instructors can address Dr. R. von Ihering, cidade de João Pessoa, Estado de Parahyba, Brazil.

Dr. James Angus Doull, professor of hygiene and public health in the School of Medicine of Western

Reserve University, has leave of absence to organize an epidemiological study for the Leonard Wood Memorial for the Eradication of Leprosy. Dr. Doull will sail on March 25 from Vancouver for the Philippine Islands, and will be absent from Cleveland for about six months. He will initiate studies on the frequency of leprosy in relation to diet, age, living conditions, contact with previous cases and other factors. These and similar studies will be continued over some years in the Philippines and possibly in other parts of the world.

DR. VICTOR NEHER, of the California Institute of Technology, is on his way to Peru, to make a further study of cosmic rays. He plans to fly over the highest peaks of the Andes, using one of the regular transport planes of Pan American Airways System specially chartered to carry his equipment.

DR. ROY W. MINER, curator of marine life at the American Museum of Natural History, sailed on February 24 to gather additional data, including motion pictures, of the Great Reef of Andros Island. He was accompanied by Chris E. Olsen, as artist. The object of the expedition is to add to the knowledge of such reefs and to enhance the display of great Bahamas coral reefs now in the museum.

PROFESSOR WILLIAM H. SELLEW, assistant director of the department of engineering research of the University of Michigan, has sailed for Germany, for a conference with Professor Planke, of Karlsruhe, an authority on air-conditioning methods.

DR. ALICE H. FARNSWORTH, associate professor of astronomy at Mount Holyoke College, is spending her sabbatical leave for the remainder of the year at the Perkins Observatory, Delaware, Ohio, pursuing special studies in spectroscopic problems.

KARL P. SCHMIDT, assistant curator of reptiles at Field Museum of Natural History, has returned to his post at the museum after six months of research on type specimens of reptiles in European museums, carried on under a fellowship awarded to him by the John Simon Guggenheim Memorial Foundation of New York.

AT its recent meeting the Committee on Scientific Research of the American Medical Association made grants to Dr. Ernest Carroll Faust, professor of parasitology, department of tropical medicine, Tulane University of Louisiana, for continuing his investigations on human strongyloidosis; to Dr. W. T. Dawson, professor of pharmacology at the University of Texas, for further work on the relations between chemical constitution and toxicity of cinchona alkaloids; to Dr. Jessie L. King and Miss Ethel Soule, of Goucher College, Baltimore, to aid in a study of the effect of cortical extract on adrenalectomized rats, and to Dr. John Guttman, of New York City, to continue his research in the laboratories of the New York Post-Graduate Medical School of Columbia University on the electric current produced by sound in the auditory apparatus.

DR. L. H. ADAMS, of the Geophysical Laboratory of the Carnegie Institution, retiring president of the Washington Academy of Sciences, delivered on February 16 an address on "The Basic Concept of the Physical Sciences."

THE third Joseph Henry Lecture before the Philosophical Society of Washington will be given by President Karl T. Compton, of the Massachusetts Institute of Technology, in the auditorium of the Cosmos Club on the evening of March 11. The subject of the address will be "High Voltage."

DR. ARTHUR H. COMPTON, professor of physics at the University of Chicago, gave a lecture on "Cosmic Rays" on February 22, at the Brooklyn Academy of Music, under the auspices of the department of physics and the Proctor Foundation of the Brooklyn Institute of Arts and Sciences.

PROFESSOR EDWARD KASNER, of Columbia University, gave three public lectures in January and February before the People's Institute. The titles of these lectures were "Numbers and Infinity," "Spaces and Dimensionality," "Geometry and Physics."

PROFESSOR H. S. JACKSON, of the department of botany of the University of Toronto, gave the annual Darwin anniversary address under the auspices of the Botanical Seminar of Michigan State College on February 14. He spoke on "Some Life Cycles of the Rusts in Comparison with those of the Red Seaweeds."

DEAN FRANK C. WHITMORE, of the Pennsylvania State College, spoke before the Central Pennsylvania Section of the American Chemical Society on February 15 on "Some Unorthodox Organic Chemistry," and on the same subject on March 1 before the Kansas City Section of the American Chemical Society.

DR. HARLAN T. STETSON, director of the Perkins Observatory of Ohio Wesleyan University, addressed the Chicago Astronomical Society on February 8 at the Adler Planetarium, on "The Correlation of Solar Activity with Radio Transmission." On February 14 he lectured before the Rittenhouse Astronomical Society at the Franklin Institute, Philadelphia, on "Some Coming Problems of Cosmic Astronomy."

ON February 17 Dr. Arthur D. Little broadcast a ten-minute talk on "Industrial Research," this being one of the series of scientific talks sponsored by General Electric Company in recognition of the

electrical industry's debt to scientific research. In the afternoon of the same day, he spoke before the weekly colloquium of the Research Laboratory at Schenectady on "Some Professional Experiences."

PROFESSOR AUGUSTE PICCARD, of the University of Brussels, gave a Norman Wait Harris lecture at Northwestern University on February 15 on "Exploring in the Stratosphere."

SIR WILLIAM B. HARDY, director of food investigation, department of scientific and industrial research, gave the Trueman Wood Memorial Lecture before the Royal Society of Arts on February 22, on "Industrial Research with Biological Material."

AT the fifteenth annual meeting of Edison Pioneers on February 11, the formation of an International Edison Foundation was announced. The foundation, which has not yet been incorporated, plans to provide fellowships in physics and chemistry in universities of the United States and other countries. American graduate students will be sent abroad and foreign students will be brought to the United States to continue their education in physics and chemistry. Dr. Arthur E. Kennelly, professor emeritus of electrical engineering at Harvard University and the Massachusetts Institute of Technology, is chairman of a committee of three appointed to confer on the fellowships.

RECENT action of the Rockefeller Foundation has approved a grant for two years, ending July 1, 1934, for a sum not to exceed $20,000 to supplement the funds of the Ohio Wesleyan University for the maintenance of the scientific program of the Perkins Observatory.

A GIFT of £500 from the Rockefeller Foundation has been made to the Molteno Institute of Parasitology of the University of Cambridge, for the purchase of instruments and for assistance in connection with investigations carried on by Professor Keilin.

ACCORDING to the *Journal* of the American Medical Association the Thomas W. Salmon Memorial Committee of the New York Academy of Medicine announces that small grants are available to physicians and others who are engaged in research work in the field of psychiatry, mental hygiene and child guidance. Workers who are interested in receiving such grants may apply to the committee, 2 East One Hundred and Third Street, New York.

DISCUSSION

IS IT "FAIR TO SAY THAT HOOKWORM DISEASE HAS ALMOST DISAPPEARED FROM THE UNITED STATES?"

I. INTRODUCTION

SINCE 1930 I have motored about 10,000 miles through the Gulf-Atlantic states, chiefly in the sandland districts. These trips have given an opportunity to compare present conditions with those of the earlier years of the century and to converse with people of all walks of life.

A striking point in these conversations has been the number of persons who believe that hookworm disease has been eradicated from this country and who cite as authority newspaper reports allegedly based on statements attributed to the Rockefeller Foundation.

The Thirteenth Annual Report (1927—for 1926) of the International Health Board of the Rockefeller Foundation contains in fact (pp. 5–6) the following paragraph:

> The diseases that the Board has chosen for special attention have been world-wide in their distribution and of great economic importance. Field research in the epidemiology of hookworm disease has *advanced knowledge* concerning the life history of the hookworm, both in its free-living larval form and in its adult relationship to the host, so that we now have a much better understanding of the disease. This knowledge has enabled *governmental agencies* to *delimit* the field of control work and to modify the methods of treatment and of prevention to such an extent that the former *administrative methods of control have been revolutionized. The results have been extraordinarily successful.* At the present time *it is fair to say that hookworm disease has almost disappeared from the United States* and is rapidly coming under control in many parts of the world. But the *great achievement* is not the social and economic rehabilitation of the more than six or seven million people who have been treated for the disease during the past ten or fifteen years; it is the development of administrative measures that will prevent millions yet unborn from ever suffering from its ravages. (Original not in italics).

Until recently I had no idea that so many people had taken the Foundation's report seriously, but during these recent trips I had to combat it so frequently that I wrote to Mr. Rockefeller, Jr., placed before him evidence as to the wide distribution of the disease in the Southern states, offered to motor with a representative of his selection in order to collect additional data for him, and urged him to take steps to modify the claim published by the Foundation. My letters were referred to the directors of the International Health Division, but up to date no retraction or modification has come to my attention.

II. ANALYSIS OF THE FOUNDATION'S CLAIM

The three essential points in the claim are:

(1) *Important discoveries in the biology of hook-*

worm: On pp. 62–72 are cited observations (regarding: 1 temperature, 2 moisture, 3 soil, 4 fermentation, 5 water in bulk, 6 salt) in connection with which the thought arises whether these are the points of "advanced knowledge"; at least, these are presented in a way that the reader (if not familiar with the literature on the subject) might easily conclude that they are new discoveries.

All six are repetitions (in new localities) of observations made 25 to 40 or more years ago.

(2) *Revolutionized administrative procedures in control:* On pp. 62–72 of the report are cited four control measures (1 shoes, 2 sanitation, 3 education, 4 treatment), but by no stretch of the imagination can these be called new. According to p. 62 of the report the egg-count method "has revolutionized administrative methods of control of the disease."

Accepting this as the basis of the "great achievement" mentioned on p. 6, the point may be raised that only two Southern states (Alabama and Tennessee) have published surveys based on this technique while officials of the Boards of Health of five Southern states have informed me that they do not use the egg-count method.

The word "delimit" (p. 6) together with the discussion (pp. 62–72) seems to indicate that the so-called "Alabama Plan" is part of the revolutionized method of control. The "Alabama Plan" was indeed revolutionary but it was short lived. It was tried out in a few counties and was promptly abandoned.

A practical question arises, namely: What "governmental agencies" applied these "extraordinarily successful" administrative methods in counties which have no health unit? Only county, state, and national health agencies come into consideration. Of the sixty-seven counties in a certain Southern State, only four have full-time units; neither the State Board of Health nor the U. S. Public Health Service applied revolutionary methods in the sixty-three other counties. It is estimated that less than five per cent. of the rural population of this particular state has whole-time local health service; who served the other ninety-five per cent.? Surely neither part-time health officers nor county physicians could accomplish the "great achievement" claimed by the Foundation.

(3) *"It is fair to say that hookworm disease has almost disappeared from the United States."* Rather definite information is available which, unfortunately and to my profound regret, does not square with this enthusiastic claim. See III.

III. Hookworm Disease in the Gulf-Atlantic States

In a recent publication (1932) I have summarized the hookworm situation as follows.

(1) The extreme case known as the "dirt eater" is much more rare now than from 1902 to 1910. (I have seen less than fifty in the past two years.)

(2) In general, the cases are much lighter than when the work first began in 1902.

(3) The disease has been reduced both in intensity and somewhat in extent, but

(4) The job has not been completed.

The fundamental problem in hookworm control is not a question of bookkeeping or microscopic examinations, but requires a change in the daily habits of hundreds of thousands of rural whites, Indians, and negroes.

In studying the prevalence and importance of hookworm disease three methods are used according to circumstances and the individual preference of the workers:

(1) *Diagnostic microscopic examinations:* Through courtesy of the State Boards of Health I was able to summarize the results of 121,388 recent (1929) examinations in Alabama, Arkansas, Florida, Georgia, Kentucky, Mississippi, Tennessee, Virginia, and West Virginia; 34,131 of the specimens (or 28.1 per cent.) were "positive."

(2) *Egg-counts:* Otto and Cort,[2] two leading apostles of the egg-count technique, have summarized evidence gathered (in Virginia, Tennessee, Kentucky, Florida, and Alabama) by themselves and "by several members of the International Health Division" and they conclude that hookworm disease has not almost disappeared from this country.

Havens,[3] of the Alabama State Board of Health (and an apostle of the egg-count method), says that "in the southern counties of Alabama—hookworm control—still is a major public health problem."

(3) *Symptomatic inspection:* During a motor trip of 5,524 miles[4] with one assistant I examined 18,649 white children in 98 graded schools, using the method of rapid symptomatic inspection (in which my personal theoretical error is about 17 per cent. as checked by the "smear method"); 6,063 of these children (or 32.5 per cent.) showed symptoms in harmony with hookworm disease; deducting 20 per cent. as theoretical error, the corrected estimate is 26 per cent.

In five rural schools in one county, I have more recently examined 429 white pupils, 266 (or 62 per cent.) of whom showed symptoms in harmony with hookworm disease; deducting 20 per cent. as theoretical error, the corrected estimate is 49.6 per cent.

IV. Summary

In view of the foregoing (and other) data I am constrained to take issue with the hookworm experts

1 Public Health Reports, Aug. 1, 1930.
2 *Jour. Amer. Med. Assn.*, July 11, 1931.
3 *J. Med. Assn. Alabama*, Jan., 1933.
4 *Southern Med. Journ.*, 1932, 189–192.

of 61 Broadway, and to submit that their claim is not "fair," in fact, it has done harm in certain localities.

V. CONCLUSION

Not only a scientific but also a great moral and humanitarian issue is involved. It is to be regretted that the Rockefeller Foundation has not complied with a duty it owes to the rural children of the South, to the scientific world, to itself and to Mr. Rockefeller (Senior and Junior), frankly and publicly to modify its *ex cathedra* claim in harmony with facts.

Economics, education, welfare, health and even human life are involved.

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CAN A PUBLICATION BE CAMOUFLAGED?

THE persistence of the faith that in some mysterious manner material may be distributed to the public without being published, by the mere device of mimeographing instead of printing, was again illustrated at the Atlantic City meeting. In at least two societies during discussions of the still vexed question of publishing abstracts, "mimeographed" as a substitute for "printed" abstracts were urged on the alleged grounds that "publication" would thus be avoided.

In his discussion "What is a Publication?"[1] Storer points out that the method used in reproduction has no bearing on the question of publication. He cites among other examples the experience of the Biological Survey with *Bird Banding Notes*, a mimeographed publication which when it was initiated bore a note on the first page of each issue—"Bird Banding Notes is not a publication and is not for general distribution." In spite of this, however, the scientific value of the contained matter soon became evident and the material was cited by other investigators. I am further informed by the Biological Survey that *Bird Banding Notes* is now being sent regularly to *Biological Abstracts* at the request of the editor of that review journal.

The *Plant Disease Reporter* is a case in point. This mimeographed serial was established in 1917, as a means of making readily available to working pathologists incidental information thought to be of transient rather than of permanent interest and which should be placed in their hands more quickly than was possible through any available printed medium. The result was a collection of mimeographed notes, the popularity of which was immediately attested by the material presented as well as by the demands for the *Bulletin*, as it was then called. In 1923, to still further emphasize the informal nature of the series, the name was changed to *Reporter*. In spite of this, the actual scientific value of the material included has been abundantly attested by its repeated citation in regularly printed scientific literature and by numerous reviews of its contents in the *Review of Applied Mycology* everywhere recognized as the standard review journal for mycological and plant pathological literature.

It is obviously possible for a group of workers in a limited field, for example, taxonomists, to bind themselves not to recognize species published by a particular method or for that matter in a special group of languages or in a particular color of ink. But general scientific matter disseminated in any form available for more or less permanent record is certainly scientifically published, whatever the method of duplicating employed.

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[1] SCIENCE, n. s., 75: 486–487, 1932.

THE AGE OF METEOR CRATER

IN SCIENCE,[1] Professor Blackwelder proposes that the Coon Butte crater in Arizona is of the Post-Tahoe epoch, some forty to seventy-five thousand years old. This decision is supported primarily by the evidence of the lake bed in the crater proper. However, in connection with the lake-bed a statement is made that I feel needs some correction. On page 559, Dr. Blackwelder states concerning a layer of rhyolitic ash in the lake bed: "The bed of volcanic ash is plainly the record of an explosive eruption somewhere in the south-western arid region. *No such eruption is known to have occurred since Pleistocene (late glacial) times.* If the age of this shower is ever determined it may afford important evidence regarding the age of Meteor Crater." (The italics are mine). It happens that the date of the shower mentioned is probably known accurately. At a meeting of anthropologists in Santa Fé during September, 1931, the Arizona University party reported the discovery of pit houses filled with ash, not too distant from the Meteor Crater. Wood was recovered from these and has been dated by Dr. Douglass, using his tree-ring calender. It had been buried by an eruption that took place in the neighborhood of 793 A. D. If the two showers are identical, then Barringer's dating of 2,000 to 3,000 years ago is probably the most acceptable of all.

Much supporting evidence for the inter-glacial dating is drawn from the formation and degradation of the talus slopes. I feel strongly that we can not draw analogies from the formation of talus where the only agents are those normal to a moist and colder climate. There is no doubt in my mind that the talus slopes were built up by the impact and explosion and not by the usual forces that disintegrate cliff faces.

[1] Vol. 76: No. 1981, pp. 557–560, December 16, 1932.

However, Dr. Blackwelder's evidence of the deeply corroded limestone blocks must be explained before a modern dating can be satisfactorily applied to the meteor fall. Whether or not sufficient heat could have been generated to partially calcine the blocks and thereby render them prone to rapid corrosion is debatable, but is still a possibility. If such calcining took place, the advanced state of corrosion might have resulted in a matter of months, even with little rainfall.

All in all, it seems that the date of the great meteor's fall is still much in doubt. Whether the fall was recent, as Barringer suggests, or ancient, as Blackwelder holds, depends upon which way you wish to interpret the known facts. I agree with Blackwelder that the layer of volcanic ash in the lake will play a great part in settling the point. Dr. Douglass' date on the ash fall that buried the timbers of the Arizona pit houses and subsequent similar information that will be massed in the near future will be keystones to the problem.

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THORNDIKE'S PROOF OF THE LAW OF EFFECT

As one of "the great majority of psychologists" who have criticized Thorndike's "law of effect,"[1] for which he now presents a positive proof,[2] I venture to suggest that this law is insusceptible of proof except on premises which many psychologists, and also many biologists, will not accept.

The statement that a "satisfying after-effect strengthens directly the connection producing it" can be maintained only under the assumption that a course of behavior consists of a number of separate and discrete acts; whereas, if the fundamental premise of all behavior be Coghill's principle that "the behavior pattern expands from the beginning throughout the growing normal animal as a perfectly integrated unit,"[3] all end-effects are consummatory, and it is not permissible to rule them out of experiments such as Thorndike records. Furthermore, Thorndike's report that the effect of a reward is noticeable in the unrewarded results that occur in proximity to those that are rewarded supports the view that learning is a self-regulating process, the parts of which are not discrete acts, but members of the whole unit of action.

What Thorndike's experiments seem to demonstrate is the effectiveness of learning without recourse to "repetition or frequency of occurrence, recency, intensity." What they do not demonstrate is that conditions have been equalized in respect of "finality, or consummatoriness, tendency to attain equilibrium and other features of the process [that] have been alleged to be adequate to explain the strengthening of connections." They do not demonstrate inadequacy of these last-named features, because these features suggest a dynamic interpretation at variance with Thorndike's assumption that learning consists in strengthening connections between parts otherwise discrete and independent.

Thorndike, himself, suggests the necessary correction to his theory when he states that "a satisfying after-effect strengthens greatly the connection which it follows directly *and to which it belongs*" (italics mine). As has been pointed out by other critics,[4] it is not *pleasure* but *success* which stamps in the right action; and it may be said to do so because the whole process is from the beginning a "perfectly integrated unit." Although the process may be disrupted, so long as learning is taking place every achievement is a consummatory process, the end-effect of which is one of finality because equilibrium has been attained. The end-effect "belongs" to what has gone before because it is an integral part of the entire unit of action. It is therefore not an "after-effect" of this action.

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[1] *Cf., Psych. Rev.*, 20: 188 *ff*. 1913.
[2] SCIENCE, 77: 173. February 10, 1933.
[3] *Cf.*, G. E. Coghill, *Arch. of Neur. and Psychiat.*, 21: 989. 1929.
[4] *Cf.*, H. Cason, *Psych. Rev.*, 39: 440, 1932; M. H. Trowbridge and H. Cason, *Jour. of Gen. Psych.*, 7: 245, 1932; E. C. Tolman, C. S. Hall and E. P. Bretnall, *Jour. of Exp. Psych.*, 15: 601, 1932.

THE EARLIEST DATED DWELLING IN THE UNITED STATES

ABOUT the year 660 A. D. some timbers were cut on the slopes of the San Francisco Mountains in Arizona and used in a dwelling. Twelve of these timbers, now a mass of charcoal, have been dated by tree-ring studies and have given us the earliest date for an American home. This dwelling is 124 years older than our previously dated oldest dwelling.

The site from which the charred timbers were secured was a rectangular pithouse (N. A. 1531), belonging to the period in Southwestern archeology known as Pueblo I.

Previous to this time the earliest dated dwelling in the Southwest was a pithouse occupied in 784 A. D. This belonged to the period called Pueblo II. We have now not only the earliest dated house but also the first reported date in Pueblo I.

These earliest dated pithouses were excavated by the Museum of Northern Arizona, Flagstaff, Arizona, under the direction of Lyndon L. Hargrave, Field Director and the timbers dated by John C. McGregor, curator of dendro-chronology.

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SCIENTIFIC APPARATUS AND LABORATORY METHODS

A HOME-MADE ELECTRICALLY-DRIVEN PSYCHROMETER

Because of the inaccuracies of the hair hygrometers used in our work, the need has developed for an accurate and convenient means of making humidity determinations in small enclosures where a sling psychrometer can not be used. For this purpose an electrically-driven psychrometer was constructed (see Fig. 1), using the thermometers from an old stationary psychrometer mounted on a frame to which is attached a small electric hair dryer. When the motor is running, air is sucked over both wet and dry bulbs, and readings may be taken after approximately two minutes.

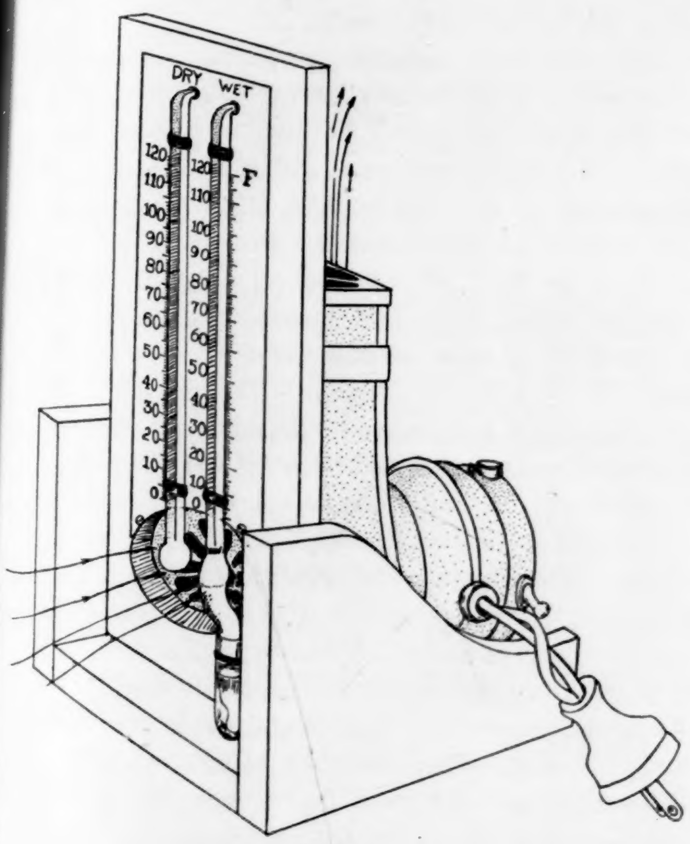

Fig. 1

Instruments operating on this principle are on the market, but those that have come to our attention are high in price and too large for our needs. This home-made instrument, the parts of which cost less than $10, was assembled for the purpose of testing its convenience for our work, but without attempting to perfect it as a precise laboratory instrument.

Many improvements are obviously desirable. The thermometers should be at least as accurate as those of a good grade sling psychrometer, and graduated on a scale to be read to one half degree F. The mercury columns should be easy to see under unfavorable conditions, as through the glass door of an incubator. For compactness the scale should cover only the usual temperature range of the work. A suitable suction device is of primary importance for furnishing an air current of as high velocity as possible, consistent with small size and freedom from excessive heating. As pointed out by Carrier and Lindsay[1], the wet bulb error may increase markedly at reduced air velocities. In assembling the instrument the thermometers should be so placed as to prevent evaporation from the wet bulb wick influencing the dry bulb, or either of the bulbs being influenced by motor heat. If the air is drawn over the bulbs from a direction other than that of the operator, the chance will be largely removed of influence from body heat or moisture when the instrument is used in the open laboratory.

The electric psychrometer was checked against a sling psychrometer under varying conditions and found in close agreement, particularly as to wet bulb temperatures. The discrepancies that occurred were such as might be ascribed to the character of the thermometers of the electric instrument, which were difficult to read with accuracy closer than one degree, and which showed errors in the dry bulb readings when checked in our chemistry department against an accurate laboratory thermometer. The influence of motor heat on the thermometers did not become apparent until some time after the maximum wet bulb depression, and then chiefly in enclosed spaces. An increase of one degree in both the dry and wet bulb readings was observed in a small incubator after five minutes' operation, but this would obviously make but little change in humidity determinations.

Our use of the instrument has been mainly in checking the hair hygrometers in our breeding cages and incubators. It has been found desirable to check each hygrometer individually under the usual conditions where it is kept. This avoids the possibility of disturbing the adjustment by handling, and makes it unnecessary to keep the hygrometer out of use for several hours for complete response to changed humidity conditions before an accurate test can be made. As some of the hygrometers have shown large errors in scale readings when calibrated over a wide range of humidities, and as it is not yet known whether these errors remain constant for any length of time, it has seemed best to make tests frequently and at the usual incubator humidity.

The electric instrument would appear to make practicable the use of a stationary psychrometer in

[1] "Temperatures of Evaporation of Water into Air," W. H. Carrier and D. C. Lindsay. *Trans. Am. Soc. Mechanical Engineers*, 1924, vol. 46, p. 739.

an incubator in which the air circulation is constant, by establishing the difference between the wet bulb reading at the regular incubator air velocity and the maximum wet bulb depression. This difference applied as a correction to the observed stationary wet bulb reading should give an approximate humidity determination. Frequent checking would be advisable to correct for any changes in air velocity or reduced evaporation from the wet bulb wick. If the incubator temperature and humidity vary only in narrow limits, a few readings at various points should form the basis of a simple chart for approximate corrections. If the air movement is not subject to variation by reason of material introduced into the incubator, the stationary psychrometer may be placed at any convenient point. Otherwise it should be located close enough to a fan to insure a constant current over the bulbs, regardless of changes of air circulation in the main body of the incubator. With low air velocities, it is particularly important that the thermometer bulbs be protected against any varying source of heat, as from the fan motor or the incubator heating elements. A stationary psychrometer has been in use in this way in an incubator for a short period with apparent success. The humidity determinations with this instrument may be more accurate, and certainly less erratic, than those obtained with our hair hygrometers, particularly in an incubator in which the frequent opening of the door tends to keep the hair instrument continually out of adjustment during the day.

For general use about the laboratory or insectary the electric instrument has advantages over the sling psychrometer in reducing the danger of breakage, and in ease of reading, as the thermometers may be read while the motor is running and the wet bulb held constant by the air current. Its special adaptability for use inside small enclosures makes it seem an instrument that is worth perfecting for entomological work.

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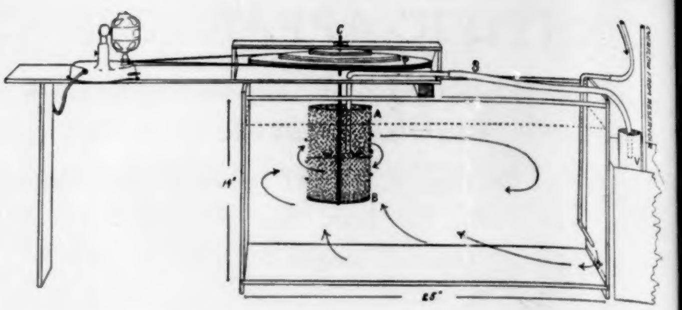
THE CURRENT ROTOR

LAST summer, while engaged in a study of post-embryonic development of mackerel and other marine fishes at Woods Hole, Massachusetts, the authors used a simple device which enables one to change water without losing small organisms that live in the aquarium. The essential feature of the apparatus is a cylinder, A, of 60 mesh or finer monel metal screen suspended in a tank and rotated by means of an electric motor. Rotation of the cylinder when placed at one end of an oblong aquarium sets up a complex system of currents the direction of which is indicated



in the accompanying illustration. Strong circular currents are formed in the immediate vicinity of the cylinder, while at the far end the water moves very gently. There is also a noticeable upward motion from the bottom of the tank.

The speed of rotation and the corresponding strength of currents may be regulated by the speed of the motor controlled through a rheostat and by means of a set of pulleys of different diameters. The dimensions of the cylinder also affect the strength of the current produced and therefore should vary according to the size of the aquarium used. The cylinder shown here is 4 inches in diameter and 6 inches long. About one inch is left above water. The tank is $25 \times 15 \times 14$ inches. The bottom of the cylinder, B, is a celluloid or monel metal disk. Non-corrosive material should also be used for the suspension rod, C, and brace wires, W. The diameter of the pulley, P, is 12 inches.

The water can be withdrawn from the tank through a siphon, S, the upper end of which is placed inside the revolving cylinder. When the cylinder is in rotation small organisms never are actually drawn against its wall, because the centrifugal force throws them away from it. They are then caught up in the circular currents and soon find themselves in quieter waters at the far end of the aquarium. In this manner the water in the tank can be changed without losing its inhabitants.

When it is desirable to supply a constant flow of water this can be accomplished by placing the lower end of the overflow siphon, S, in a vessel, V, adjusted so that the top of it is level with the water in the aquarium. The water is introduced from a reservoir, in which it is kept at constant level. If necessary the water from a laboratory faucet can be filtered through glass wool to remove sediment and other foreign matter.

The revolving cylinder not only provides for changing water without losing small organisms that are kept in the aquarium, but also by setting the water in motion it prevents the accumulation of the organisms and their sticking to the bottom. In this respect it can be used instead of a plunger jar.

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